BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Spacecraft Radiation Limits Imposed by X-Ray Astronomy Experiments - Case 710

DATE: August 29, 1968

FROM: F. F. Tomblin

ABSTRACT

Values of X-ray fluxes observed or anticipated in solar and stellar astronomy experiments are given. It is pointed out that the local X-ray flux from the spacecraft due to nuclear power systems or other X-ray emitting devices should not exceed some small fraction of the isotropic X-ray background of space origin. These requirements may be difficult to meet if appreciable radiation from spacecraft sources such as isotopic dynamic power systems, are involved.

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MEMORANDUM FOR FILE

I. INTRODUCTION

The purpose of this note is to summarize some of the prominent sources of X-rays in a spacecraft environment which may cause some interference with sensitive X-ray astronomy experiments. An attempt is made to establish a reasonable upper limit on the X-ray astronomy experiment. The actual sources of the X-ray radiation from a manned spacecraft will be discussed in some detail in the following sections.

II. X-RAY FLUXES FROM ASTRONOMICAL SOURCES

A. Solar Radiation

Figure 1 summarizes the range of results of several experiments measuring the solar X-ray flux from 1 to 10^4keV. The flux falls off rapidly for energies >1 keV. Such X-rays are generated primarily by recombination of electrons with ions in the sun's corona. It is important to remember that the solar X-ray flux is highly dependent on the flare activity. During a flare the solar X-ray emission usually increases several orders of magnitude with the largest changes occurring in the high energy portion of the spectrum.

Balloons, rockets and satellites are currently being used as vehicles for these measurement. Because even a small amount of the atmosphere absorbs essentially all radiation below 20 keV down to optical wavelengths, the low energy X-ray experiments are performed from rockets or satellites. The higher energy gamma radiation flux ($E > \sim 100$ keV) penetrates to lower altitudes accessible by balloons which provide longer observation times than that available from rocket flights.

B. Diffuse Background

Measurements over the past six years have confirmed the existence of X-radiation which is nearly isotropic. This radiation is essentially "noise" which is superimposed over all localized X-ray sources. Figure 2 indicates the level of the isotropic background flux and the degree of error in the flux as observed from many experiments. Note that the level decreases from 100 to 10^{-4} photons/cm^2 sec keV as the energy increases from 1 to 1000 keV.

There are two theories on the origin of the almost isotropic radiation which are most widely accepted. One such theory due to Felten and Morrison[2] involves the inverse Compton scattering of the "3° K" black body photons resulting from a postulated "Big Bang" origin of the universe. In such a model these low energy photons, of isotropic distribution, gain energy when scattered by energetic electrons in intergalactic space. However, unless one assumes that present electron sources are less than they were in the past, this argument does not give a value large enough for the isotropic flux.

Another theory which also has the same quantitative failing is that of Friedman, Byram and Chubb[3]. They conjecture that the isotropic background is due to the sum of the heretofore unresolved X-ray sources of extragalactic origin. To obtain numerical agreement with observations, Friedman et al assume a large number of peculiar galaxies having X-ray emission rates much in excess of our own. Silk[4] has recently suggested a more plausible argument. He asserts that in early stages of galaxy formation, intense X-ray emission occurs. The high background then would be primarily due to the contribution from such "early type" galaxies.

C. Example of Stellar X-Ray Spectrum

For completeness, an example of a sky scan from a rocket experiment is given in Figure 3 showing several X-ray sources. It is seen that the flux from strong stellar sources is highly directional and is many times the isotropic level.

III. X-RAY ASTRONOMICAL MEASUREMENTS

The relatively new field of X-ray astronomy uses many of the well developed techniques for detecting astronomical X-radiation. Film, gas filled proportional counters, and scintillation crystals are the most popular detectors. These systems are usually flown in sounding rockets or balloons. Several X-ray experiments, particularly for solar studies, have been flown on unmanned satellites.

Figure 4 shows the configuration of a typical X-ray astronomy system. A detector which is sensitive primarily to charged particles (cosmic rays) surrounds the actual X-ray detector. An anticoincidence circuit eliminates those counts received in both the X-ray and particle detectors.

The X-ray detectors themselves are gas-filled, quenched proportional counters for the region <40 keV and scintillation crystal types above 40 keV. Solid state detectors with much better energy resolution than either proportional counters or scintillation crystal types above 40 keV are currently difficult to use because of cooling requirements and small size, but their increased use is anticipated with improvement in the state of the art. X-ray film is used with grazing incidence telescopes currently planned for the solar ATM mission.(5) Such systems are excellent for work where <20 sec of arc resolution is required. The small effective aperture of such systems restricts their use to strong sources such as the sun.

IV. X-RAY ASTRONOMY - SPACECRAFT INTERFACE PROBLEMS

A. Tolerable Levels of X-Ray Flux

From the above, it is clear that there will always be a certain level of X-ray radiation impinging upon the spacecraft due to the isotropic background. It is thus not essential (or practical) to require a totally quiescent environment for X-ray astronomy experiments. From Figure 3 it is apparent that an upper limit smaller than the isotropic background is required for observations of many sources. This limit could be relaxed if only very strong sources were to be observed, and, in general, would vary depending on the strength of the X-ray sources under observation. Nevertheless, this is a small flux, and some effort will be required to prevent exceeding this level.

It should be pointed out that certain types of anticoincidence circuits could reduce the detrimental effects of some of the spacecraft sources. The introduction of such systems, however, increases the possibility of experiment failure.

In addition to a general flux requirement several other precautions must be observed.

1. If the local source of radiation is not independent of the orientation of the X-ray "telescope" with respect to the spacecraft, this may be confused with the identification of a stellar source. Directional calibration of the background must be possible and the source should be of limited solid angle and flux.

2. Any flux of contaminating X-rays must be free of "lines" superimposed over the continuum spectrum, or if such lines must be present, their characteristics must be sufficiently well known so that they may be subtracted out. X-ray astronomers are particularly interested in observing gamma radiation lines at specified energies which may be due to radioactive decay through nuclear excited states. Such information would be valuable in determining the types of nuclear reactions occurring particularly in supernovae.[6]

3. Time variations in the flux must be minimized since these will lead to false information concerning the time variation of astronomical sources themselves.

B. On-Board X-Radiation Sources

The various "on-board" sources of X-radiation are now considered. While the list is by no means complete, the topics discussed should indicate most of the areas which could generate a sizeable X-ray flux.

1. Bremsstrahlung

The sudden deceleration of fast charged particles in the presence of nuclei results in secondary radiation by the moving charge known as bremsstrahlung. Bremsstrahlung from charged particles, particularly moderate energy electrons, interacting with the surface of the spacecraft and the shielding near the X-ray detectors represents a possible source of difficulty for X-ray astronomy experiments. (We do not concern ourselves here with the direct interaction of the charged particle-induced bremsstrahlung in the detector itself because this problem is not created by the presence of the spacecraft; however, it is by no means insignificant.) The flux of high energy electrons (>1 BeV) of galactic origin is so low that bremsstrahlung from such electrons would not be a problem.

In near-earth orbit one of the most severe problems is the electrons of moderate energy in the South Atlantic Anomaly (SAA). Because of the localized nature of the SAA it would be possible to turn off all sensitive experiments during the passage through the SAA. At any rate, ionization detectors and most unshielded X-ray sensors would be saturated from the direct interaction of the charged particles in the SAA and rendered useless for X-ray astronomy observations for these orbits. Low orbits (<150 NM) can miss the SAA almost completely.

2. On-Board Radioactive Sources

Several types of on-board radioactive sources have been proposed for Apollo spacecraft. Pm^{147} is to be used in the form of luminous tape or buttons to make such items as switch tips, docking rings and hatch handles visible. Pm^{147} is a beta and gamma emitter. Most of the beta radiation is absorbed in the plastic container. The gamma radiation is less than 120 keV and will be easily absorbed by material in the spacecraft. Up to 70 curies of Pm^{147} have been proposed for use in the first Apollo mission on the outside of the spacecraft.[7] At 10m distance, this would amount to approximately $10^2 \frac{\text{photons}}{\text{cm}^2\text{sec keV}}$ at 100 keV. With no shielding, as seen from Figure 3, this flux would swamp out most X-ray sources. However 1 cm of lead would reduce this by at least 10 orders of magnitude, with lower energy radiation (<100 keV) being absorbed even more efficiently. Suitable shielding of the detector could thus reduce the flux from Pm^{147} many orders of magnitude below the isotropic background at all energies of interest. While there is no apparent problem with interference from such radioactive sources, all necessary tests should be performed to make certain that the shielding is indeed effective. Moreover, it would be highly advantageous not to place unnecessarily large amounts of radioactive luminescent tape on spacecraft with X-ray astronomy experiments.

3. Isotope-Dynamic Power System Radiation

A potentially severe radiation source can be the gamma radiation from an isotope thermoelectric generator. The impurity content in such power systems drastically changes the level of gamma radiation. For example, in a Pu^{238} heat source the Pu^{236} impurity contributes greatly to gamma radiation. Thus there is hope for lower radiation levels with purified supplies.

Figure 5 indicates the approximate anticipated photon flux at 10 meters from an amount of Pu^{238} capable of 25 kilowatts of thermal power.[12] (The detailed isotropic content is listed in the figure). This source is a candidate for an isotope-dynamic power system for manned spacecraft use. Also indicated in Figure 5 is the flux from the Pu^{238} power source which would pass through 1 cm and 10 cm of lead. Note that with 1 cm of lead, the radiation level from the power source exceeds the isotropic flux at approximately 200 keV, and at 800 keV it is $\sim 10^3$ times the isotropic flux. With 10 cm of lead shielding the situation is improved considerably. The radiation from the Pu^{238} source exceeds the isotropic flux level only above 2 MeV, and the largest excess of this level is by a factor of ~ 3 at 3 MeV.

It appears that with considerable shielding the 25 kilowatt Pu^{238} isotopic power source can be made acceptable for low energy (ie <1 MeV) gamma ray astronomy experiments. It is clear that without this shielding experiments would be impossible to conduct in a spacecraft employing such an isotopic power source.

V. CONCLUSION

In order to assure the successful operation of X-ray astronomy experiments, the flux of spacecraft-generated X-radiation should not exceed some small fraction of the isotropic background flux. Using this criterion, some of the difficulties which may be present with the integration of X-ray astronomy experiments into a large spacecraft have been discussed. Radiation sources other than nuclear power systems may present some problems, but apparently they may be overcome. The radiation from nuclear power sources without very heavy shielding remains a serious hazard to X-ray astronomy experiments. This problem should be studied in more detail using the fluxes from radioisotopic thermoelectric generators.

F. F. Tomblin

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Attachments
References
Figures 1-5

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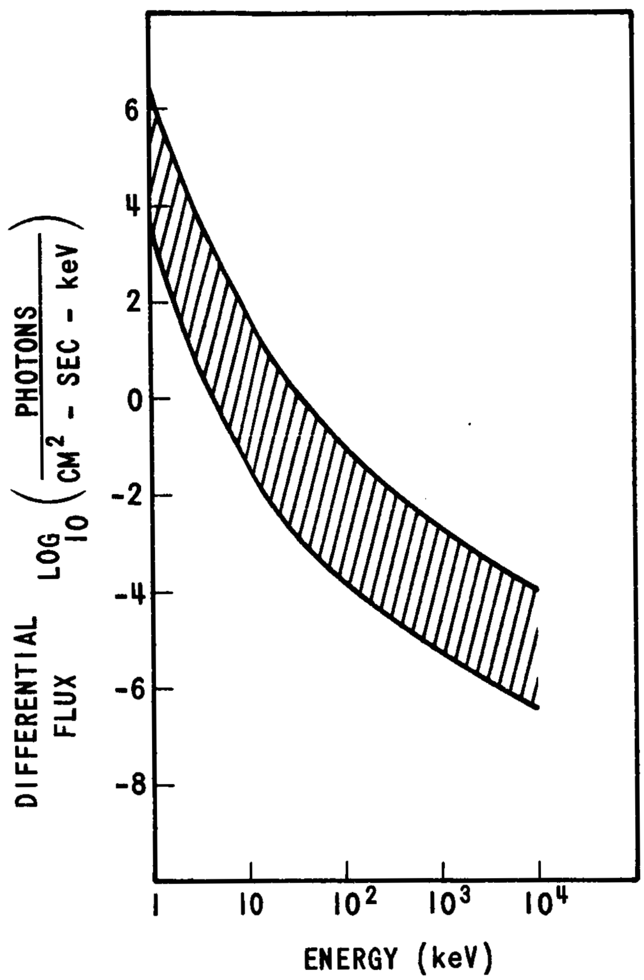

FIGURE 1 - SOLAR X-RAY SPECTRUM FROM 1 - 10,000 keV (REFERENCES 9,10).

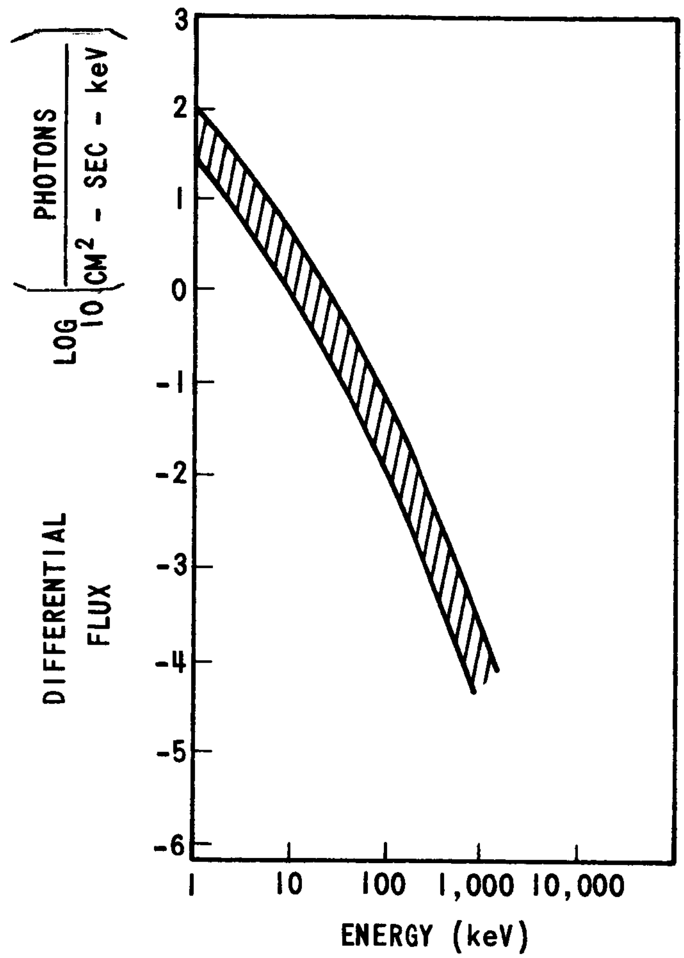

FIGURE 2 - ISOTROPIC X-RAY FLUX (4π STERADIANS) vs. ENERGY (REFERENCE 1).

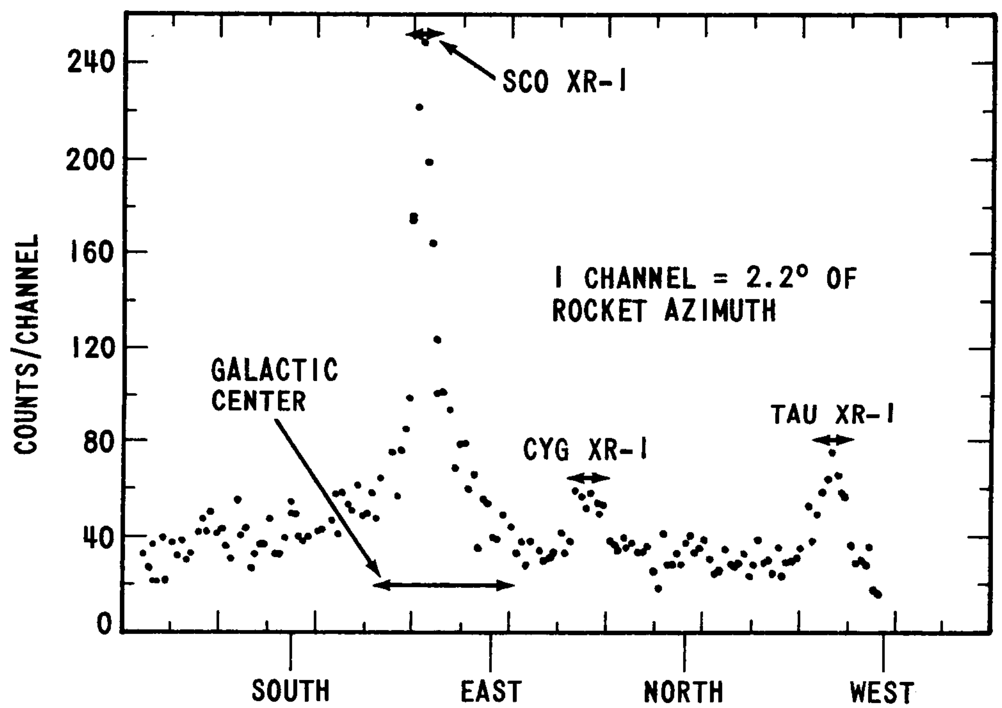

FIGURE 3 - TOTAL NUMBER OF X-RAYS WITH ENERGY BETWEEN 4.3 AND 28 keV OBSERVED FOR THE 282 SEC THAT THE ROCKET WAS ABOVE 95 KM AS A FUNCTION OF AZIMUTH DURING THE JULY 28, 1966, ROCKET FLIGHT. (REFERENCE 11)

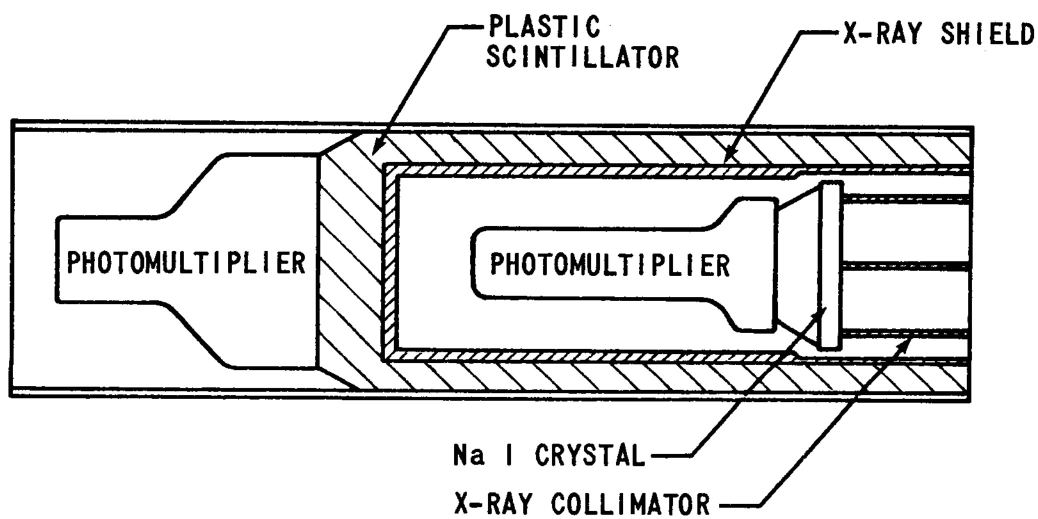

FIGURE 4 - TYPICAL X-RAY DETECTOR. COLLIMATION AND SHIELDING FOR THE Na I CRYSTAL ARE SURROUNDED BY A COSMIC-RAY DETECTOR USED IN ANTI-COINCIDENCE TO REDUCE BACKGROUND. (FROM REFERENCE 8)

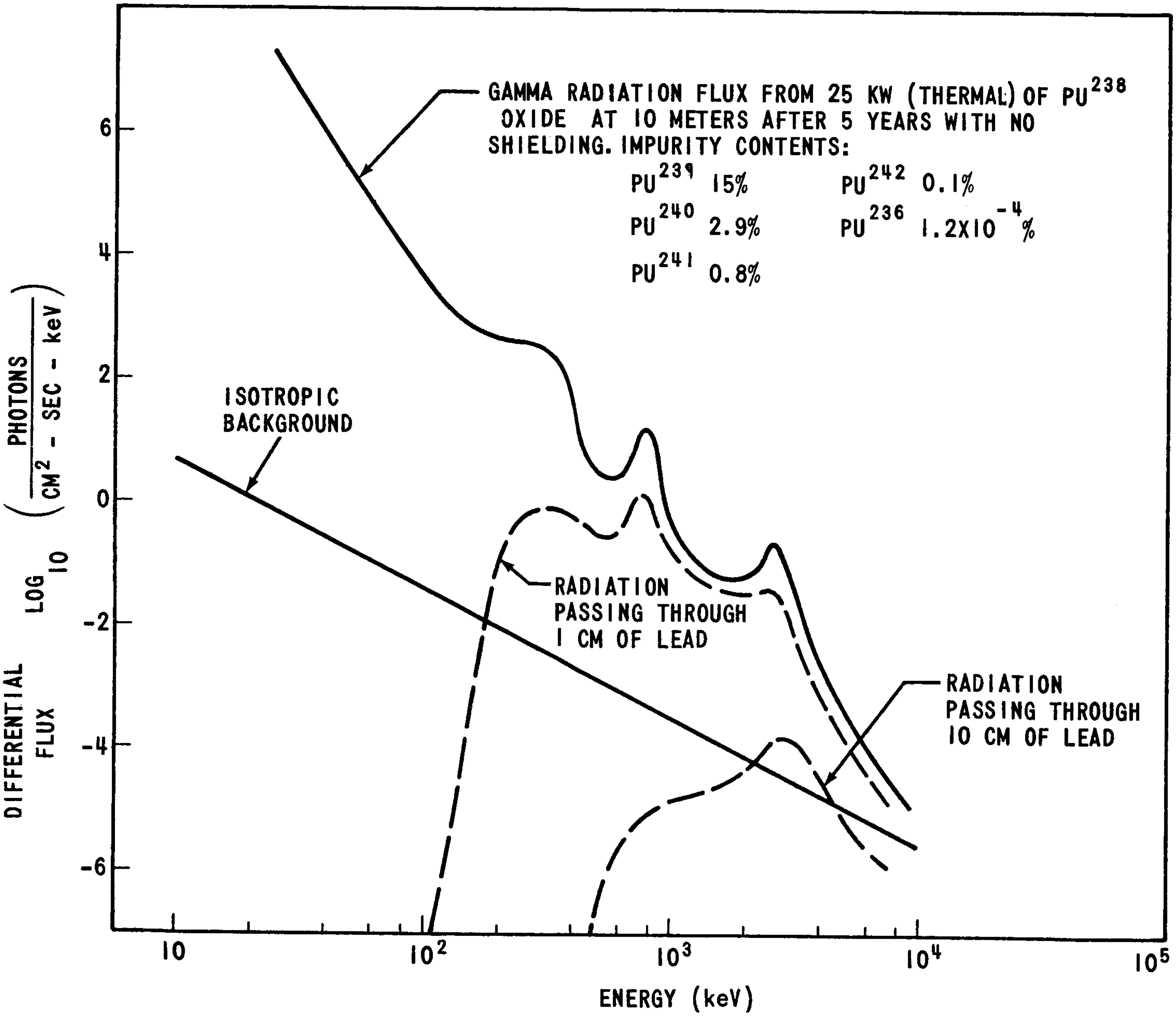

FIGURE 5 - X-RADIATION FROM PU^{238} (OXIDE) ISOTOPIC THERMAL SOURCE. ALSO INCLUDED ARE RADIATION OF THE THERMAL SOURCE WHICH WOULD PASS THROUGH 1 AND 10 CM OF LEAD, AND THE ISOTROPIC BACKGROUND RADIATION.

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